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# The effects of unilateral hand contractions on conscious control in early motor learning

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ABSTRACT

*Hemisphere asymmetry can be influenced by hand contractions. Brain imaging studies have indicated that pre-performance left-hand contractions may reduce verbal-analytical engagement in motor planning, whereas pre-performance right-hand contractions may increase verbal-analytical engagement in motor planning. This study examined whether a pre-performance left-hand contraction protocol reduced verbal-analytical engagement during practice of a golf putting task, thereby causing implicit motor learning. Forty-eight golf-novices were randomly allocated to left-hand contractions, right-hand contractions or no hand-contractions (control) groups. A line bisection task was conducted as a manipulation check of whether hemisphere asymmetry occurred. All participants practiced a golf putting task, with their allotted hand contraction protocol performed for 30 sec before every ten putts. Thereafter, participants completed two retention tests (blocks of single-task putting) before and after one transfer test (a block of dual-task putting). Different objective and subjective measures of verbal-analytical engagement were collected. Golf putting accuracy and kinematics were assessed. Additionally, mood-state as a function of hemisphere asymmetry was measured. The line bisection task did not reveal a hemisphere asymmetry effect of the different hand contraction protocols. All groups equally improved during practice; however, the no hand-contraction (control) group showed better performance during both retention tests compared to left-hand and right-hand contraction groups. All groups performed worse in the dual-task transfer test. The objective and subjective measures of verbal-analytical engagement revealed no effect of hand contractions. General mood-state decreased for all groups from pre- to post-practice. Unilateral hand contractions prior to practicing the golf-putting task did not affect performance differently from the no hand-contraction (control) group. However, hand contractions resulted in worse performance compared to the no hand-contraction group during the retention tests, and dual-task transfer performance disrupted performance in all groups. No differences in verbal-analytical engagement were evident. Consequently, left-hand contractions did not promote implicit motor learning. Possible explanations and recommendations for future studies are discussed.*

## 1. Introduction

Pre-performance unilateral hand contraction protocols have been revealed to cause hemispheric asymmetry (Gable, Poole, & Cook, 2013; Harmon-Jones, 2006; Peterson, Shackman, & Harmon-Jones, 2008; Schiff, Guirguis, Kenwood, & Herman, 1998). Contralateral couplings between the hands and the brain mean that left-hand contractions activate the right hemisphere and suppress the left hemisphere, whereas right-hand contractions activate the left hemisphere and suppress the right hemisphere. Beckmann, Gröpel, and Ehrlenspiel (2013) and Gröpel and Beckmann (2017) showed that left-hand contractions prior to skill execution led to better motor performance under pressure compared to right-hand contractions among semi-professional athletes. The left hemisphere of the brain is known to be responsible for verbal-analytical processes, whereas the right hemisphere is responsible for visual-spatial processes (De Renzi, 1982), so Beckmann et al. (2013) suggested that better performance under pressure was a consequence of left-hand contractions suppressing the left hemisphere and thus suppressing disruptive verbal-analytical

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processes. Verbal-analytical processes have been linked to conscious control of movement (e.g., Gallicchio, Cooke, & Ring, 2016; Zhu, Poolton, Wilson, Maxwell, & Masters, 2011), which is associated with disrupted motor performance under pressure (e.g., Masters & Maxwell, 2008; Zhu et al., 2011).

Hoskens, Bellomo, Uiga, Cooke, and Masters (2020) were the first to use cortical activity to investigate whether pre-performance unilateral hand contraction protocols influenced verbal-analytical engagement in motor planning during a golf putting task. Verbal-analytical engagement in motor planning is thought to influence cortical synchronization (i.e., EEG connectivity) between the verbal left temporal (T7) and the motor planning mid-frontal (Fz) locations on the scalp in the final seconds before and during movements (e.g., Gallicchio et al., 2016; Zhu et al., 2011). Hoskens et al. (2020) revealed that pre-performance left-hand contractions resulted in lower T7-Fz connectivity during performance of a golf putting task compared to right-hand and no hand-contraction protocols, and this was interpreted to indicate reduced verbal-analytical engagement in motor planning during performance. Furthermore, pre-performance right-hand contractions caused increased T7-Fz connectivity, which may indicate greater verbal-analytical engagement compared to left-hand contractions or no hand-contractions.

Based on the findings of Hoskens et al. (2020), this study examined whether left-hand contraction protocols have potential to cause implicit motor learning by reducing verbal-analytical engagement during motor planning. In contrast to explicit motor learning, implicit motor learning is designed to minimizes verbal-analytical processes during movement planning and execution by specifically reducing the amount of verbal-analytical knowledge that a performer can access explicitly (e.g., Masters, 1992; Masters & Maxwell, 2004; Maxwell, Masters, & Eves, 2003). It has been claimed that implicit processes are more efficient at guiding movements and result in robust performance under pressure compared to explicit processes (Masters, 1992; Masters, van Duijn, & Uiga, 2019). Different approaches have been established to promote implicit motor learning. Masters (1992) asked people practicing a golf putting task to also carry out a secondary task (continuously generating random letters of the alphabet in time with a metronome). The secondary task used up resources normally available to process information about the putting task, so participants learned implicitly. Maxwell, Masters, Kerr, and Weedon (2001) reduced the amount of errors during golf putting practice by starting from close to the target and then gradually moving further away in increments of 25cm. Maxwell et al. (2001) found that reducing the amount of errors during practice lowered the likelihood that participants would use verbal-analytical processes to consciously improve their performance, presumably because they were successful. Zhu et al. (2015) used cathodal (i.e., inhibitory) transcranial direct current stimulation (tDCS) to reduce activity in the left dorsolateral prefrontal cortex (DLPFC), which is associated with working memory processes and verbal learning mechanisms (Brunoni & Vanderhasselt, 2014). Zhu et al. (2015) found evidence of suppressed verbal-analytical engagement during movement planning and execution, reflective of implicit motor learning.

Here we examine whether a pre-performance left-hand contraction protocol can be used to promote implicit motor learning by suppressing verbal-analytical engagement in the task and thereby minimizing accumulation of explicit knowledge. Three groups of participants practiced a golf putting task. Prior to each block of trials, participants completed left-hand contractions, right-hand contractions or no hand-contractions. Similarly to Goldstein, Revivo, Kreitler, and Metuki (2010) a line bisection task was used as a manipulation check of whether hand contractions caused hemispheric asymmetry.[1] After a recovery interval they completed a test phase, which consisted of two retention tests separated by a dual-task transfer test. The retention tests were used to establish effects on performance (mean radial error) after boredom and fatigue had abated. The dual-task transfer test was used as an indicator of implicit motor learning. Explicitly learned motor tasks are typically disrupted by a secondary task that requires verbal-analytical processing, because performance of the motor task also requires verbal-analytical processing. Implicitly learned motor tasks, on the other hand, are not disrupted by a secondary task that requires verbal-analytical processing, because performance of the motor task does not require verbal-analytical processing (e.g., Maxwell, et al., 2001). Subjective and objective measures of technique change during practice were also used to assess whether hand contraction protocols influenced verbal-analytical engagement in performance. Changes in technique are associated with verbal-analytical engagement in performance as people test hypotheses in a search for motor solutions (Maxwell et al., 2001; Maxwell, Masters, & Poolton, 2006). Additionally, following the first retention test, participants were asked to recall the final position of the ball on each trial. We speculated that participants would have better recall if they had been using verbal-analytical processes to consciously test hypotheses based on the outcomes of putts on previous trials.

Finally, measures of general and motor related mood-states were assessed prior to and after golf putting practice to control for conflicting mood states that may have been caused by the hand contraction protocols.[2]

Our primary interest was in the effects of hand contractions on motor learning. We predicted that left-hand contractions, which raise activity in the right hemisphere and lower activity in the left hemisphere, would reduce verbal-analytical engagement in movements during practice of a golf putting task, thus promoting

[1] In most people, attention is spatially biased to the left, which causes them to judge the center of a horizontal line to be more to the left than the right (for a review see, Jewell & McCourt, 2000). This phenomenon, pseudoneglect (Bowers & Heilman, 1980), is thought to occur because the right hemisphere of the human brain is dominant for spatial attention processes (e.g., Roberts & Turnbull, 2010; Turner, Hahn, & Kellogg, 2017) and is strongly connected with the contralateral hemispace (e.g., Corbetta, Miezin, Shulman, & Petersen, 1993). If hand contraction protocols influence hemisphere activity, they should influence spatial bias. Goldstein et al. (2010), for example, revealed that left-hand contraction protocols resulted in greater bias to the left in the line bisection task, whereas right-hand contractions resulted in greater bias to the right.

[2] The 'valence hypothesis' suggests that the left hemisphere is associated with positive emotions, whereas the right hemisphere is associated with negative emotions (see Davidson, 1992, for a review). Consistent with the 'valence hypothesis', evidence suggests that right-hand contractions promote more positive emotions (i.e., higher left hemisphere activity) but left-hand contractions promote more negative emotions (Propper, Dodd, Christman, & Brunye, 2017; Schiff & Lamon, 1994; Schiff & Truchon, 1993).

implicit motor learning. We therefore expected left-hand contractions to result in fewer self-reported technique changes, lower kinematic variability in technique (reflective of less hypothesis testing), worse recall of performance outcome and better performance on a dual-task transfer test compared to right-hand and no hand-contractions.

## 2. Methods

### *2.1 Participants and Design*

Forty-eight people were recruited to participate in this study (Mean age = 24.46 years, SD = 5.85 years, 26 female). All participants had normal/corrected vision and self-reported being right-hand dominant. A between subjects design was adopted, with the participants randomly allocated to a left-hand contractions, right-hand contractions or no hand-contractions (control) group. Participants completed a practice phase followed by a test phase (see *Procedure*). The study received ethical approval from the University Human Research Ethics Committee.

### *2.2 Task*

The hand contraction protocols required participants to firmly contract a stress ball at a self-paced rate either with their left hand or right hand. In the no hand-contraction (control) group, participants placed their hands in their lap and held them still.

The golf putting task consisted of hitting a regular-size golf ball (4.7 cm diam.) to a target on an artificial grass surface, using a golf putter (80 cm length) (see Figure 1.A). The target (a 12 cm diam. black circle) was positioned 1.9 m from the starting position. We used a flat target instead of the traditional golf putting hole in order to yield precise measures of performance, in terms of both accuracy (i.e., mean radial error) and directional bias (i.e., directional error) (see Figure 1.B). The SAM PuttLab system (SAM PuttLab, Science motion GmbH, Munich, Germany, www.scienceandmotion.de), with an overall sampling rate of 210 Hz, was used to obtain kinematics of the putter (SAM PuttLab reports manual, 2010).

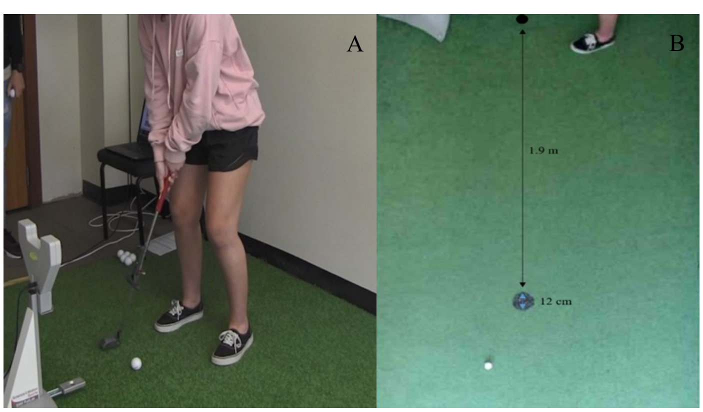


Figure 1: Experimental set up of the golf putting task. A) SAM PuttLab set up B) dimensions of the target.

### *2.3 Measures*

#### *2.3.1 Line bisection – Manipulation check*

The line bisection task was conducted prior to and after a single pre-practice hand contraction protocol before motor practice, and once after motor practice, to confirm whether hand contractions influenced hemispheric asymmetry, which would result in greater leftward bias for left-hand contractions and greater rightward bias for right-hand contractions (e.g., Goldstein et al., 2010; Jewell & McCourt, 2000).

The line bisection task required participants to mark the exact middle of two straight horizontal lines (18 cm length) presented consecutively on a sheet of paper. The lines were offset either to the left or to the right on the sheet of paper (Goldstein et al., 2010). Deviation from the middle point of the line (i.e., 9 cm) was calculated as percentage bias error (Scarisbrick, Tweedy, & Kuslansky, 1987). The mean percentage bias error of the two trials was computed. Positive scores reflect prejudice to mark further to the right side of the line, suggesting increased left hemisphere activation, whereas negative scores reflect prejudice to mark further to the left side suggesting increased right hemisphere activation (Goldstein et al., 2010).

#### *2.3.2 Measures of verbal-analytical engagement in the putting task*

Self-reported technique changes: Following the practice phase, participants answered questions related to technique changes (i.e., ‘I tried different ways of hitting the target’ and ‘I changed my technique while doing the golf-putting task’). The items were rated on a 6-point Likert Scale ranging from 1 (strongly disagree) to 6 (strongly agree). The mean score of both questions was taken.

Kinematics: Golf putting swing kinematics were computed to provide insight into technique changes during practice phase and the test phase (e.g., Maxwell et al., 2003). The kinematics obtained from the SAM PuttLab data were standard deviation (SD) of the putter velocity at impact (mm/sec) and putter face angle at impact (degrees) (see, Malhotra, Poolton, Wilson, Omuro, & Masters, 2015).

Performance outcome recall: Following the first retention test, participants were asked to recall the general dispersion of their putts by indicating the number of putts that had come to rest in each area of a diagrammatic representation of the target area (see Figure 2). Recall performance was calculated as the absolute difference between the reported numbers and the actual number of balls in each area.

Golf putting performance: Three performance scores – radial error (cm), directional error (cm) and short/long error (cm) – were computed for each golf putt, using ScorePutting software (written in National Instruments LabVIEW), which uses photographs from a camera placed directly above the putting target (Neumann & Thomas, 2008).

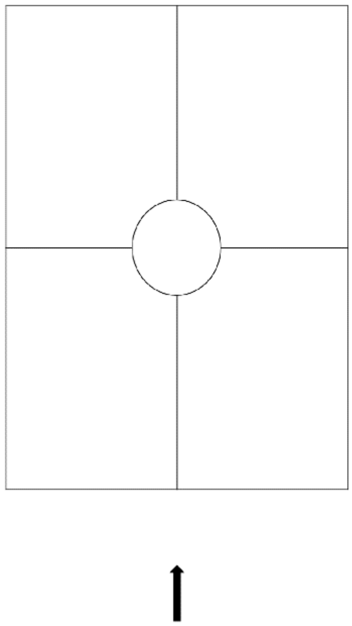

Figure 2: Recall sheet

#### *2.3.3 Mood-state*

Overall mood-state was measured prior to and after golf putting practice, using one question (i.e., 'overall, my mood at the moment is'), which was rated on a Likert-type scale ranging from -10 (very unpleasant) to 10 (very pleasant).

### *2.4 Procedure*

Participants were informed about the context of the study, signed an informed consent form and completed the demographics and overall mood-state questionnaires prior to the start of the experiment. They then completed the line bisection task before and after performing a single hand contraction protocol for 45 sec (left-hand, right-hand or no hand-contractions). After this, seven blocks of ten golf putting trials were completed, with each block preceded by a 30 sec hand contraction protocol (left-hand, right-hand or no hand-contractions).[3] Upon completion of the 70 trials, participants again completed the line bisection task. The self-report measures of technique changes and of overall mood-state were administered. Finally, following a rest interval (10 min), a test phase was performed. The test phase consisted of a dual-task transfer test (10 trials of putting and tone counting) sandwiched between two retention tests (10 trials of single-task putting each). During the dual-task transfer test, participants heard low (500 Hz) and high (1000 Hz) pitched tones (interval 1000 msec) played through computer software (Labview Application Builder 2010, National Instruments Inc., Austin, TX) in a randomized order. Participants were asked to count the number of low-pitched tones. The absolute deviation between number of tones reported and the number of tones presented was calculated as a performance percentage. After completion of retention test 1, participants were asked to recall the final resting position of each of their putts.

### *2.5 Statistical Approach*

Percentage bias error (i.e., deviation left or right of exact middle, cm) during the line bisection tasks was subjected to a 3 x 3 repeated measures analysis of variance (ANOVA): Group (Left-hand contractions, Right-hand contractions, No hand-contractions) x Test (Pre-practice test 1, Pre-practice test 2, Post-practice test). To determine whether pseudoneglect occurred, we conducted one-sample t tests (critical value 0.00 cm deviation, i.e., exact middle of the line). Self-reported technique changes and performance outcome recall scores were analysed by one-way ANOVA: Group (Left-hand contractions, Right-hand contractions, No hand-contractions). For the practice phase, the SAM PuttLab measures (SD face impact and velocity impact), radial error, directional error and short/long error were subjected to a 3 x 7 repeated measures ANOVA: Group (Left-hand contractions, Right-hand contractions, No hand-contractions) x Block (B1, B2, B3, B4, B5, B6, B7). For the test phase, the SAM PuttLab measures, radial error, directional error and short/long error were subjected to a 3 x 3 repeated measures ANOVA: Group (Left-hand contractions, Right-hand contractions, No hand-contractions) x Test (Retention 1, Dual-task transfer, Retention 2). Tone counting performance during the dual-task transfer test was subjected to a one-way ANOVA: Group (Left-hand contractions, Right-hand contractions, No hand-contractions).

Overall mood-state was subjected to a 3 x 2 repeated measures ANOVA: Group (Left-hand contractions, Right-hand contractions, No hand-contractions) x Test (Pre-practice phase, Post-practice phase).

Sphericity and normality checks were performed and controlled for when needed. When main effects or interactions were found, separate ANOVAs, post-hoc tests (Bonferroni corrected) or polynomial trend analyses were performed. Effect sizes are reported as partial η squared ($\eta p^2$). The statistical tests were performed using SPSS (IBM, version 26.0) computer software. Significance was set at $p = .05$ for all statistical tests.

## 3 Results

### *3.1 Line bisection – Manipulation check*

No main effects of Group, $F(2,45) = 0.04$, $p = .958$, $\eta p^2 < .01$, or Test, $F(2,90) = 0.66$, $p = .520$, $\eta p^2 = .01$, were revealed for percentage bias error. There was also no Group x Test interaction, $F(4,90) = 0.44$, $p = .777$, $\eta p^2 = .02$ (see Table 1).

Given that there were no Group or Test effects and no Group x Test interaction, we collapsed all bias errors together (*M* deviation = -0.54 cm, SD = 2.39) and conducted a single one-sample *t* test (critical value 0.00 cm; exact middle of line) to establish whether spatial bias was evident. A significant difference from 0.00 cm was not evident, $t(48) = -1.55$, $p = .127$.

[3] We used multiple hand contraction protocols to maintain the effects of the hand contraction protocols on brain activity.

Table 1: Mean and SD percentage bias error in each group by line bisection test.

| Group | Left-hand contractions | | Right-hand contractions | | No hand-contractions | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD |
| Pre-practice test 1 (%) | -0.09 | 3.72 | -0.16 | 2.28 | -0.87 | 3.39 |
| Pre-practice test 2 (%) | -0.73 | 4.06 | -0.02 | 3.13 | -0.38 | 3.34 |
| Post-practice test (%) | -0.68 | 3.34 | -1.13 | 2.25 | -0.78 | 2.12 |

*Note.* A negative mean value means a more leftward bias, and positive value a more rightward bias.

### *3.2 Measures of verbal-analytical engagement*

#### *3.2.1 Self-reported technique changes*

The mean score on the self-report technique change questions was 4.34 (SD = 1.06) for the left-hand contraction group, 4.22 (SD = 1.09) for the right-hand contraction group and 4.53 (SD = 1.09) for the no hand-contraction group. No main effect of Group was evident, $F(2,47) = 0.34$, $p = .714$, $\eta p^2 = .02$.

#### *3.2.2 Kinematics*

*Practice phase:* The SD of velocity at impact revealed a main effect of Block, $F(4.66,139.64) = 19.50$, $p < .001$, $\eta p^2 = .39$, but no main effect of Group, $F(2,30) = 0.77$, $p = .474$, $\eta p^2 = .05$, or Group x Block interaction, $F(12,180) = 0.26$, $p = .994$, $\eta p^2 = .02$ (see Figure 3). Post-hoc analysis of the Block effect revealed a quadratic trend, ($p < .001$, $\eta p^2 = .63$); SD of velocity at impact decreased sharply over the first blocks of trials and then levelled off.

The SD of face angle at impact revealed a main effect of Block, $F(6,180) = 4.11$, $p = .001$, $\eta p^2 = .12$, but no main effect of Group, $F(2,30) = 0.45$, $p = .643$, $\eta p^2 = .03$, or Group x Block interaction, $F(12,180) = 0.66$, $p = .785$, $\eta p^2 = .04$ (see Figure 4). Post-hoc analysis of the Block effect revealed a linear trend ($p < .001$, $\eta p^2 = .44$); SD of face angle at impact reduced gradually across blocks of trials.

*Test phase:* SD of velocity at impact did not reveal a significant main effect of Group, $F(2,37) = 2.40$, $p = .105$, $\eta p^2 = .12$, or of Block, $F(1.73,63.93) = 1.16$, $p = .319$, $\eta p^2 = .03$. There was no Group x Block interaction effect, $F(4,74) = 0.15$, $p = .964$, $\eta p^2 = .01$ (see Figure 3).

SD of face angle at impact did not reveal a significant main effect of Group, $F(2,37) = 0.45$, $p = .643$, $\eta p^2 = .02$, or of Block, $F(2,74) = 1.69$, $p = .191$, $\eta p^2 = .04$, and there was no Group x Block interaction effect, $F(4,74) = 0.58$, $p = .677$, $\eta p^2 = .03$ (see Figure 4).

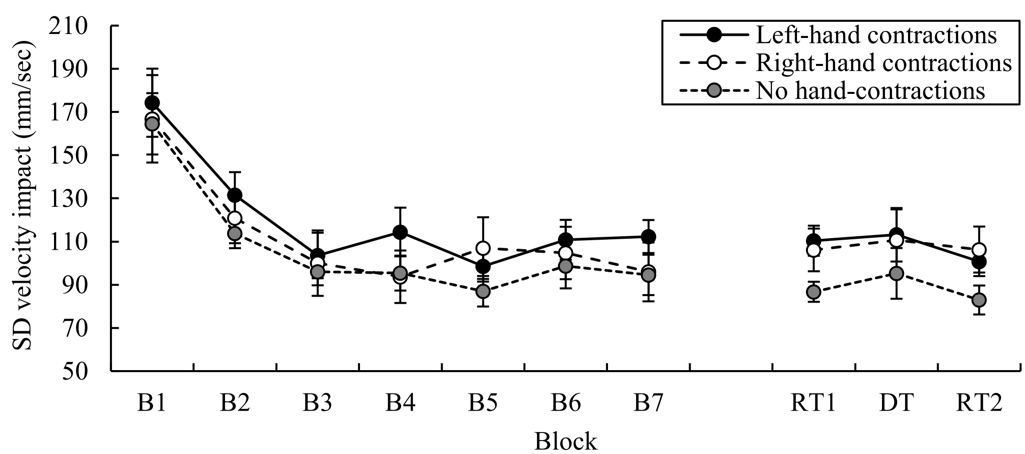


Figure 3: SD of velocity at impact for each block of trials during the practice and test phases, as a function of hand contraction protocol. Error bars represent the standard error of the mean.

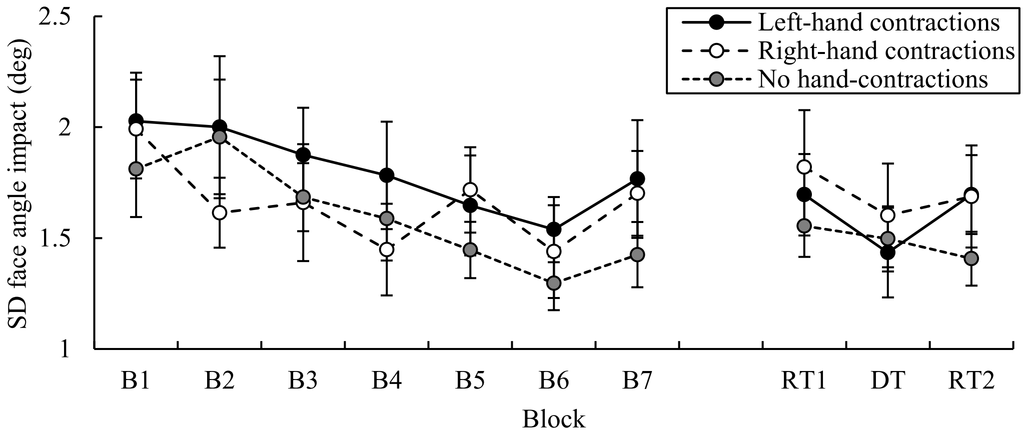


Figure 4: SD of face angle at impact for each block of trials during the practice and test phases, as a function of hand contraction protocol. Error bars represent the standard error of the mean.

### 3.2.3 Performance outcome recall

Mean recall accuracy was calculated as the number of correctly recalled final ball positions out of the ten trials of retention test 1. Mean recall accuracy was 4.63 (SD = 2.80) for the left-hand contraction group, 5.5 (SD = 1.71) for the right-hand contraction group, and 5.38 for the no hand-contraction (control) group. No main effect of Group was found, $F(2,47) = 0.46$, $p = .635$, $\eta p^2 = .02$.

### 3.2.4 Golf putting performance

*Practice phase:* For radial error, a main effect of Block was revealed, $F(6,246) = 28.06$, $p < .001$, $\eta p^2 = .41$, but there was no main effect of Group, $F(2,41) = 1.01$, $p = .375$, $\eta p^2 = .05$, and a Group x Block interaction was not evident, $F(12,246) = 0.63$, $p = .817$, $\eta p^2 = .03$ (see Figure 5). Post-hoc analysis of the Block effect revealed a linear trend ($p < .001$, $\eta p^2 = .76$), suggesting that constant incremental reductions in radial error occurred across blocks of trials.

For directional error, main effects were not evident for Group, $F(2,41) = 0.26$, $p = .771$, $\eta p^2 = .01$, or for Block, $F(6,246) = 1.04$, $p = .399$, $\eta p^2 = .03$, and a Group x Block interaction was not evident, $F(12,246) = 0.99$, $p = .405$, $\eta p^2 = .05$ (see Figure 6).

For short/long error, a main effect of Block was evident, $F(4.78,19581) = 10.19$, $p < .001$, $\eta p^2 = .20$. However, neither a main effect of Group, $F(2,41) = 1.60$, $p = .215$, $\eta p^2 = .07$, nor a Group x Block interaction effect were evident, $F(12,246) = 0.94$, $p = .504$, $\eta p^2 = .04$. Post-hoc analysis of the Block effect revealed a linear trend ($p < .001$, $\eta p^2 = .46$), suggesting that constant incremental reductions in short/long error occurred across blocks of trials (see Figure 7).

*Test phase:* For radial error, main effects were evident for Group, $F(2,40) = 4.62$, $p = .016$, $\eta p^2 = .19$, and Block, $F(2,80) = 15.87$, $p < .001$, $\eta p^2 = .28$. However, there was not a Group x Block interaction, $F(4,80) = 1.14$, $p = .343$, $\eta p^2 = .05$ (see Figure 5). Post-hoc analysis of the Group effect revealed significantly lower radial error in the no hand-contraction group compared to both the left-hand contraction group ($p = .030$) and the right-hand contraction group ($p = .047$). Radial error did not differ between the left-hand contraction and right-hand contraction groups ($p = 1.00$). Post-hoc analysis of the Block effect revealed significantly greater radial error during the dual-task transfer test, compared to retention test 1 ($p < .001$) and retention test 2 ($p < .001$). Radial error did not differ in the two retention tests ($p = 1.00$).

For directional error, no main effects were evident for Group, $F(2,40) = 0.51$, $p = .605$, $\eta p^2 = .02$, or Block, $F(2,80) = 1.32$, $p = .274$, $\eta p^2 = .03$. There was no Group x Block interaction, $F(4,80) = 0.37$, $p = .829$, $\eta p^2 = .02$ (see Figure 6).

For short/long error, a main effect for Block was revealed $F(1.82,72.88) = 15.85$, $p <.001$, $\eta p^2 = .28$, but there was no main effect of Group, $F(2,40) = 3.00$, $p = .061$, $\eta p^2 = .13$. A Group x Block interaction was not evident, $F(4,80) = 1.49$, $p = .213$, $\eta p^2 = .07$ (see Figure 7). Post-hoc analysis of the Block effect revealed a quadratic trend ($p < .001$, $\eta p^2 = .31$), suggesting that distance errors peaked during the dual-task condition.

### 3.2.5 Tone counting accuracy

Mean tone counting accuracy was 92% (SD = 0.08%) for the left-hand contraction group, 92% (SD = 0.09%) for the right-hand contraction group and 93% (SD = 0.06%) for the no hand-contraction (control) group. There was no significant difference in tone counting accuracy between groups, $F(2,45) = 0.19$, $p = .828$, $\eta p^2 = .01$.

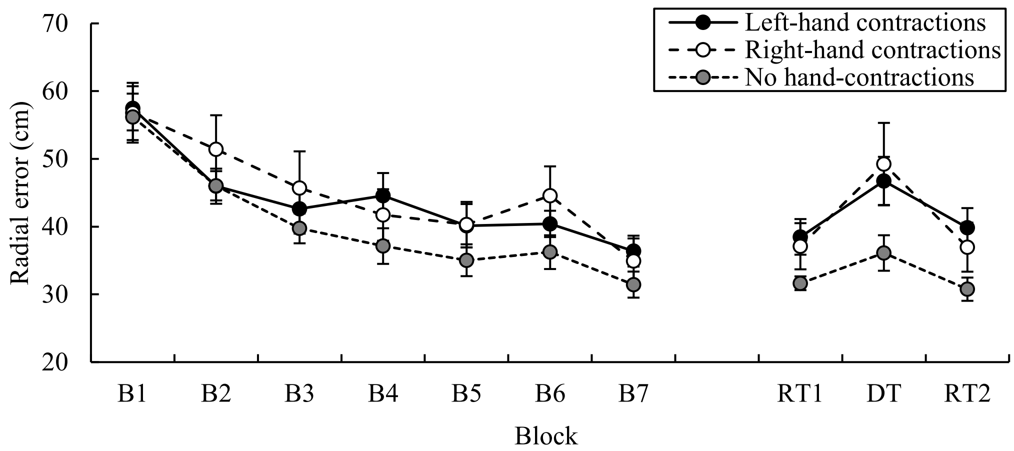


Figure 5: Radial error during each block of trials in the practice phase and the test phase, as a function of hand contraction protocol. Error bars represent the standard error of the mean.

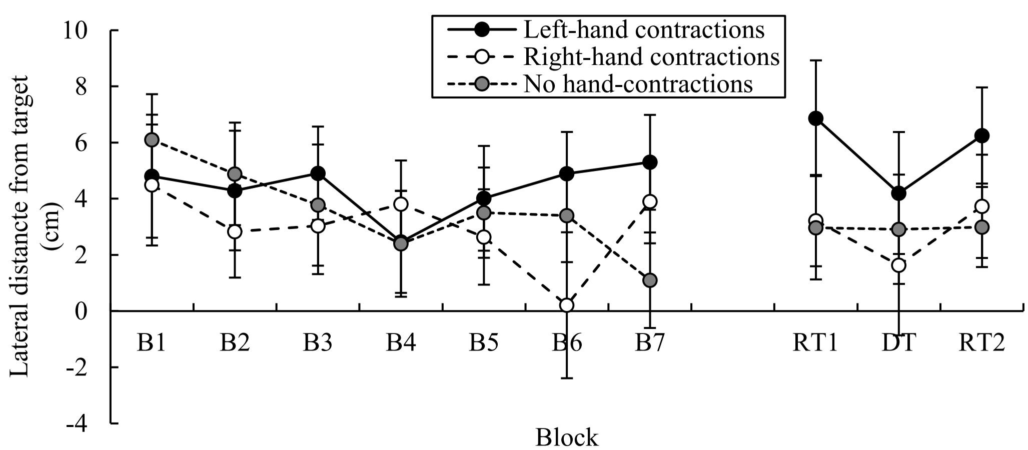


Figure 6: Directional error during each block of trials in the practice phase and the test phase, as a function of hand contraction protocol. Positive values represent putts to the right of the target. Error bars represent the standard error of the mean.

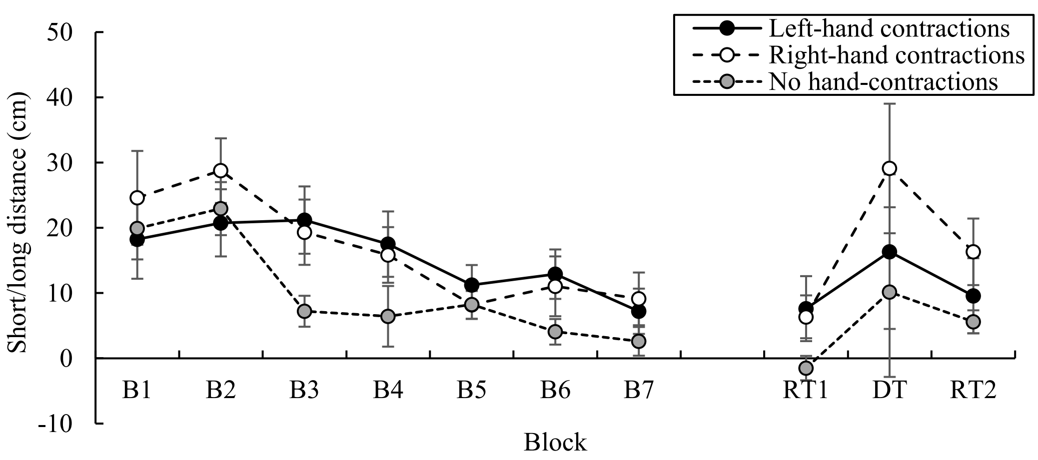


Figure 7: Short/long error during each block of trails in the practice phase and the test phase, as a function of hand contraction protocol. Positive values represent long errors. Error bars represent the standard error of the mean.

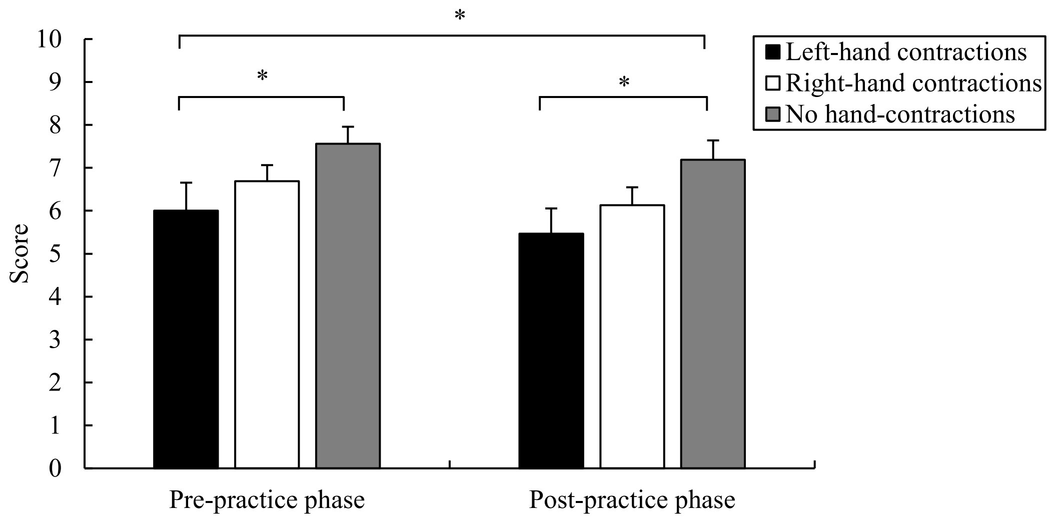


Figure 8: Mean score on the general mood-state question before and after the practice phase, as a function of hand contraction protocol. Error bars represent the standard error of the mean. $*p < .05$.

### *3.3 Mood-state*

For overall mood-state, there were significant main effects of Group, $F(2,45) = 3.93$, $p = .027$, $\eta p^2 = .15$, and Test, $F(1,45) = 9.53$, $p = .003$, $\eta p^2 = .18$ (see Figure 8). A Group x Test interaction was not evident, $F(2,45) = 0.14$, $p = .872$, $\eta p^2 = .01$. Post-hoc analysis of the Group effect revealed that overall the left-hand contraction group reported significantly lower mood compared to the no hand-contraction control group ($p = .023$), but the right-hand contraction group did not differ from either of the other groups ($p$'s > .39). Significantly lower mood was evident after the practice phase ($M = 6.10$) compared to before the practice phase ($M = 6.56$) for all groups.

## 4 Discussion

This study is the first to examine the effects of hand contractions on motor learning. Hoskens et al. (2020) suggested that pre-performance left-hand contractions reduced verbal-analytical engagement in motor planning, so we predicted that left-hand contractions during practice would promote implicit motor learning by reducing explicit processes (e.g., hypothesis testing) that are usually associated with verbal-analytical engagement in performance. However, our measures suggested that there was no effect of hand contraction protocols on verbal-analytical engagement in performance. Self-reported levels of technique change and changes in kinematics (SD of velocity and angle at impact) during the practice phase were not different between the groups. Changes in SD of velocity were consistent with the power law of practice, suggesting that early in practice participants putted the ball with too much or too little force, but attuned quickly to the force (and thus velocity) that was appropriate. Changes in SD of face angle, however, improved gradually throughout practice. Additionally, recall of performance outcome after retention test 1 was not different between groups. Furthermore, no between-group differences in golf-putting performance accuracy (radial error, directional error and short/long error) were evident during the practice phase, with all groups becoming more accurate gradually over blocks. During the test phase, both hand contraction groups demonstrated worse golf-putting performance than the no hand-contraction (control), suggesting that hand contractions interfered with the learning process. Additionally, dual-task putting performance was lower in all three groups compared to single-task performance (both retention tests), suggesting that performance of the golf putting task was equally resource demanding in the groups. The kinematic measures did not change significantly during dual-task performance, however. Possibly, the measures were not sufficiently sensitive to detect change in performance.

One possible explanation for the findings is that the hand-contraction protocols did not induce hemispheric asymmetry. This assumption is supported by the results of the line bisection tasks, which showed that all groups displayed a similar bias when asked to mark the exact middle of the horizontal lines. The results are not consistent with the findings of Goldstein et al. (2010), who revealed greater leftward bias for left-hand contractions. However, our hand contraction protocol differed from other protocols that have been used, raising questions about the impact of timing and duration of hand contractions on hemispheric asymmetry. Other studies have also failed to demonstrate an effect of hand contractions on spatial bias (Baumann, Kuhl, & Kazén, 2005; Moeck, Thomas, & Takarangi, 2019; Propper, McGraw, Brunye, & Weiss, 2013; Turner et al., 2017), so the line bisection task simply may not be a suitable manipulation check in this context.

It is well established that skilled performance is characterised by cortical specificity, with resources gated towards regions that are essential for performance and inhibited in regions that are less essential for performance (e.g., Gallicchio & Ring, 2019; Hatfield & Kerick, 2007; Haufler, Spalding, Santa Maria, & Hatfield, 2000); however, research has shown that this cortical specificity can be reversed under pressure conditions (e.g., Hatfield et al., 2013). Beckmann et al. (2013) demonstrated that pre-performance left-hand contractions, prior to task performance prevented choking under pressure compared to right-hand contractions for semi-professional athletes. Beckmann et al (2013) argued that left-hand contractions might have prevented choking by increasing right hemisphere (visuo-spatial) activity and reducing left hemisphere (verbal-analytic) activity, [4] thereby shifting patterns of cortical activity towards those associated with more automatic performance. For novices, however, optimal patterns of cortical activity may differ or may need to develop over time (Bellomo, Cooke, & Hardy, 2018; Gallicchio, Cooke, & Ring, 2017). Accordingly, the use of pre-performance hand contractions may help to maintain previously established (optimal) patterns of cortical activity in experts but not deliver the same performance-benefits for novices at the initial stages of motor learning. Instead, both right-hand contractions and left-hand contractions may disrupt learning compared to no hand-contractions. Future research should adopt neurological measures (e.g., electroencephalography) to gain more insight into the cognitive processes that are influenced by the hand contraction protocols during practice. Furthermore, adding more practice trials or comparing experts with novices, might reveal whether the hand contraction protocols have a different effect on later stages of learning.

It is also possible that hand contractions may have been distracting or have caused muscle fatigue, which might have interfered with golf putting performance. Alternatively, the influence of left-hand contractions may have been superseded by the activation of the muscles of the right hand during putting because participants used predominantly their dominant hand to power and/or guide their movements. Future research should therefore control for this possibility by utilizing tasks that do not require use of the hands (e.g., soccer penalty kicking).

Participants reported significantly lower overall mood-state following the practice phase, compared to before the practice phase, but this change in mood was similar for all groups, and thus cannot be attributed to a specific hand contraction protocol. This finding is not consistent with Propper et al. (2017) and Schiff and Lamon (1994), who revealed that hand contractions influenced mood-state. Specifically, right-hand contractions resulted in more positive mood-state, presumably as a result of activating the left hemisphere. However, the experiments by Propper et al. (2017) and Schiff and Lamon (1994) did not examine emotional states associated with motor practice, which may explain why the results of our study are not similar. Rather than focus on emotions, studies have increasingly started to examine approach and avoidance behaviour in relation to hemisphere asymmetry (see Kelley, Hortensius, Schutter, & Harmon-Jones, 2017, for a review). This is based on evidence that hemisphere activity is more related to approach or avoidance motivation that might occur to the emotions that are felt (Harle & Sanfey, 2015; Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003). Consequently, approach and avoidance should be addressed in further studies of hand contraction effects on motor learning, as this might also have an effect on cognitive processes and behaviour during motor learning (e.g., Koch, Holland, & van Knippenberg, 2008; Saarikallio, Luck, Burger, Thompson, & Toiviainen, 2013).

A final limitation is that although we used a study design similar to Zhu et al. (2015), we did not use an appropriately delayed retention test. Delayed retention tests are often conducted after at least a day, allowing effects of practice, such as boredom or fatigue, to fully dissipate, and processes associated with learning to consolidate (e.g., Shea, Lai, Black, & Park, 2000).

To conclude, we found no effect of hand contractions on self-report or objective measures of verbal-analytical engagement by novices when performing golf putting trials. Golf putting performance in the retention tests was worse for both hand contraction groups compared to the no hand-contraction (control) group, and all groups performed worse when asked to carry out a secondary task (tone counting) concurrently with golf putting. Taken together, these initial findings suggest that left-hand contractions are unlikely to promote implicit motor learning. However, given that the study did not include an explicit learning control group and that the manipulation check calls into question whether the hand contraction protocols even had the desired effect on hemisphere asymmetry, we feel that further studies are needed in order to gain a fuller understanding of the potential effect of hand contractions on implicit and explicit motor learning.

## Conflict of Interest

The authors declare no conflict of interests.

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[4] Mesagno, Beckmann, Wergin, and Gröpel (2019) have since modified this argument. On the basis of evidence that hand contractions cause cortical relaxation over the entire scalp (Cross-Villasana, Gropel, Doppelmayr, & Beckmann, 2015), they argued that reduced left hemisphere activity following left hand contractions is a function of cortical relaxation in both hemispheres.

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